Control of Powder Properties for Food Materials by Fine Grinding with Various Pulverizers

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Content

• Background and objectives
• A new approach to optimize blade geometry of a mechanical mill using a computer simulation
• Effects of types of mill on powder properties
• How to control powder properties including pasting property, color and flavor by fine grinding
Background

Stress mechanisms in particle size reduction

a) Pressure between two surfaces (compressive)
b) Cutting between two surfaces
c) Shear stress
d) Impact with a solid surface
e) Impact with another particle
f) Attrition (friction)
Typical particle distributions of powder ground by three kind of forces
Background

Stress mechanisms in particle size reduction

a) Pressure between two surfaces
b) Cutting between two surfaces
c) Shear stress
d) Impact with a solid surface
e) Impact with another particle
f) Attrition (friction)

Changes in powder properties:
particle size (surface area),
crystal structure etc.

Product quality for food materials:
dissolution, absorption, stability etc.
Objectives

1. Development of a new approach to optimize blade geometry of a mechanical impact mill for control of powder properties.

2. Control of powder properties for food materials by fine grinding
A new approach to optimize blade geometry of a mechanical impact mill

Numerical simulation:
  Particle trajectories in a mechanical impact mill
  Impact energy

Experiment:
  Calcium carbonate particles ground in a mechanical mill with various rotor blades
  Particle size distribution, crystallinity changes
Grinding mechanisms of a mechanical impact mill

- a) collision against walls (blades and stator)
- b) collision with another particle
- c) attrition on walls
- d) cutting by blades
- e) shear in a narrow gap between blade tip and stator
Experimental apparatus
Cross-sectional diagram of a mechanical impact mill

Table Dimensions

- \( D_1 = 150 \text{mm} \), \( D_2 = 136 \text{mm} \)
- \( W_1 = 20 \text{mm} \), \( T = 6 \text{mm} \)
- \( c = 2 \text{mm} \), \( H_1 = 40 \text{mm} \)
**Numerical simulations using Fluent**

**Flow field**
- Realizable k-ε turbulent model
- Conditions:
  - Rotation speed $\omega$: 14,000 min$^{-1}$
  - Inlet velocity $u_z$: 12 m/s

**Particles Trajectories**
- Lagrangian dispersed phase model
- Conditions and assumptions:
  - Particle diameter $D_p$: 100 $\mu$m
  - Particle density $\rho_p$: 1,400 kg/m$^3$
  - Coefficient of restitution: 1 (perfectly elastic)
  - Particle-particle interaction: negligible
  - Effect of particles on air properties: negligible
  - Change in particle size: negligible
  - Number of particles: 100 (mono-sized)
  - Injected velocity $v$: 0 m/s

**Calculation region**
- Blade ($u_\theta = r \omega$)
- Stator wall
  - $(u_z=0,u_r=0,u_\theta=0)$
- Rotor disc
- Inlet
  - $u_z=12$ m/s
- Outlet

Periodic boundary conditions are applied at the rear side and front side of the calculation region.
Calculated results for blade angle $\theta_B = 0$
Impact positions with stator wall

Rebounding velocity in z-direction

Typical trajectories of a particle with a diameter of 100µm for various blade angles
Number of impacts and impact velocity as a function of blade angle.
The definition of impact energies per particle mass

\[
E_n = \frac{1}{N_t} \sum_{i=1}^{N_t} \sum_{j=1}^{n_i} \left( \frac{1}{2} v_{n, i, j}^2 \right) \quad (2)
\]

\[
E_t = \frac{1}{N_t} \sum_{i=1}^{N_t} \sum_{j=1}^{n_i} \left( \frac{1}{2} v_{t, i, j}^2 \right) \quad (3)
\]

where

- \( N_t \) = total number of injected particles [-]
- \( n_i \) = total number of impacts for an \( i \)th particle [-]
- \( v_n \) = normal component of impact velocity [m/s]
- \( v_t \) = tangential component of impact velocity [m/s]

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**Normal impact energy \( E_n \) and tangential impact energy \( E_t \) by the computer simulation**
Estimation of change in crystallinity:

$$\text{Intensity Ratio} = \frac{I}{I_0}$$

X-ray diffraction (XRD) patterns for calcium carbonate particles ground in the impact mill with various blade angles
Changes in particle size and crystallinity of calcium carbonate particles ground in the impact mill with various blade angles.
Another application of the optimizing approach - effects of blade angle on properties of potato starch particles -

Material: Potato starch
Mill: the mechanical impact mill with different blade angles
Measurement
  Particle size
  Crystallinity
  X-ray diffraction (XRD)
  Pasting properties:
    Rapid Visco Analyser (RVA)
RVA (Rapid Visco Analyser, Newport Scientific Pty. Ltd.)

Pasting state in the RVA

Parameters for pasting properties
- **Pasting temperature**: Temperature where viscosity first increases
- **Peak viscosity**: Maximum viscosity

Typical RVA pasting curve

Viscosity measurement
- Paddle
- Canister
- Heating/cooling

Swollen

Broken

water

Typical RVA pasting curve
Potato starch particles ground in the impact mill with various blade angles and a ball mill.
X-ray diffraction (XRD) patterns and the definition of crystalline index for potato starch particles

Crystalline index (Wakelin *et al.*)

\[
C = \frac{\int |I_s - I_a| d \cdot 2\theta}{\int |I_c - I_a| d \cdot 2\theta}
\]  

where

- \(I_c\): intensity of feed particles (crystalline)
- \(I_a\): intensity of ball-milled particles (amorphous)
- \(I_s\): intensity of pulverized particles
Changes in crystallinity for potato starch particles ground in the impact mill with various blade angles.
Pasting properties of potato starch particles ground in the impact mill with various blade angles
Changes in properties of potato starch particles ground in the impact mill with various blade angles
Effects of types of mill on powder properties

Material: Potato starch

Mills: a mechanical impact mill, a jet mill, a ball mill

Measurement:
Particle size, crystallinity, pasting properties

Mechanical mill: Blade Mill
Jet mill: Super Jet Mill
Structure of a mechanical impact mill (Blade Mill)
Comparison of particle size distributions for wheat bran ground in optimized and conventional mechanical mills.
SEM photos of wheat bran powder ground in optimized and conventional mechanical mills.
Comparison of specific energy consumption in the optimized mechanical mill, a conventional mechanical mill and a jet mill
Structure of a jet mill (Super Jet Mill)
Classifying ring

Inner wall structure (calculation region)

(a) Velocity vectors

(b) Typical particle trajectories ($D_p = 10 \mu m$)

Calculated results in the Super jet mill
Relation between particle size distribution of product and mixture ratio (color toner).

Conventional jet mill

Super Jet Mill
Particle size distributions of potato starch particles ground in various mills
SEM photos of potato starch particles ground in various mills

(a) Feed
(b) Jet mill
(c) Mechanical mill
(d) Ball mill
X-ray diffraction (XRD) patterns for potato starch particles ground in various mills
RVA (Rapid Visco Analyser) profile of potato starch particles ground in various mills
How to control color of powder by grinding

Material: Green tea

Method:
  Grinding temperature and particle size
  Type of mills: mechanical mill, jet mill, disc attrition mill

Measurement(color):
  A tristimulus colorimeter CR-310 (Minolta)

Raw material (leaves of green tea)  →  Ground product
CIE (International Committee on Illumination)  
L* a* b* color coordinates

Chroma: $C^* = \sqrt{(a^*)^2 + (b^*)^2}$

L* : Lightness of a color  
  (ranges from black at 0 to white at 100)

C* : Chroma (color saturation or purity)
Effect of grinding temperature on color of green tea powder for various particle sizes
Particle size distributions of green tea powder ground in different types of mill
SEM photos of green tea powder ground in various mills

(a) Jet mill  
(b) Mechanical mill  
(c) Disc attrition mill
Effect of particle size on color of green tea powder
How to control flavor of powder by grinding

Material: Buckwheat, green tea
Method:
  - Grinding temperature and particle size
  - Type of mills; mechanical mill, jet mill, disc attrition mill
Measurement (flavor):
  - GC-MS (Gas Chromatograph-Mass Spectrometer) system:
    - GC-17A&QP-5000 (Shimazu, Japan)

(a) Flowers  (b) Husks  (c) Grains  (d) Flour
Example of Gas chromatogram for buckwheat flour ground in the mechanical mill.

- **To = 10 °C**
- **To = 50 °C**

**Mechanical mill**

Buckwheat flour

$D_{p50}=30\mu m$
Effect of grinding temperature on flavor of buckwheat flour ground in the mechanical mill
Effect of grinding temperature and particle size on flavor intensity of green tea powder

Outlet temperature $T_0 \, [^\circ C]$

Flavor intensity

- 8 $\mu$m
- 12 $\mu$m
Effect of type of mill on flavor of green tea powder
Conclusions

(1) The simulated impact energies are useful parameters for determining the optimum blade angle of the mechanical mill.

(2) The optimum blade angle for efficient changes in crystallinity of particles and pasting properties is different from that for size reduction.

(3) The particle size has a significant effect on color of powder. The grinding temperature and particle size influence flavor of powder.

(4) Types of mill strongly influence pasting properties of potato starch.